Overview of Calibration and Validation Plans for the Ozone Mapping and Profiler Suite (OMPS)*

by L.E. Flynn

with material taken from presentations by Didier Rault, Richard Buss, Quinn Remund, Scott Asbury, Maria Caponi, Gary Heckman, Changwoo Ahn, Eric Beach, Glen Jaross, Shuntai Zhou, Trevor Beck and Paul Lee
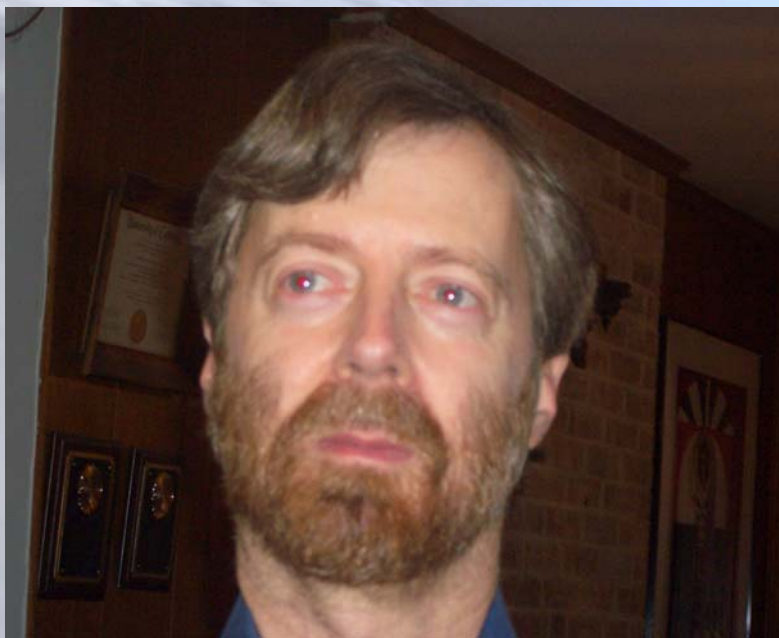
*Subtitles: Lessons Learned, and Building on Heritage

NPOESS

Northrop Grumman
Raytheon

DoD • DOC • NASA

OMPS Algorithms, Calibration and Validation

- **NESDIS Center for Satellite Applications and Research (StAR)**
  - Algorithm Development
  - Cal/Val of Ozone Sensors/Products
  - Analysis and Verification

- **Multiple Ozone Responsibilities**
  - Chair, NPOESS OMPS Operational Algorithm Team
  - Member, NASA/NOAA Ozone Processing Team
  - SBUV/2 Calibration Scientist
  - Member, NPOESS Data Exploitation Team
  - Co-Chair, NESDIS Atmospheric Chemistry Satellite Products Oversight Panel

- **Awarded Two NOAA Bronze Medals**
- **PhD, Applied Mathematics, 1987**

Lawrence E. Flynn
NOAA

Outline

- **Testing by instrument manufacturer**
  - Verify performance/requirements on-ground
  - Traceability of standards
- **Creating Sensor Data Records (SDR)**
  - parameters and gap work
- **Cal/Val Task Network and analysis**
- **Bundled Environmental Data Record (EDR) products**
- **In-orbit calibration and design heritage**
- **Soft calibration and algorithm design heritage**
- **Current inter-comparisons and results**
- **Limb profiler challenges**
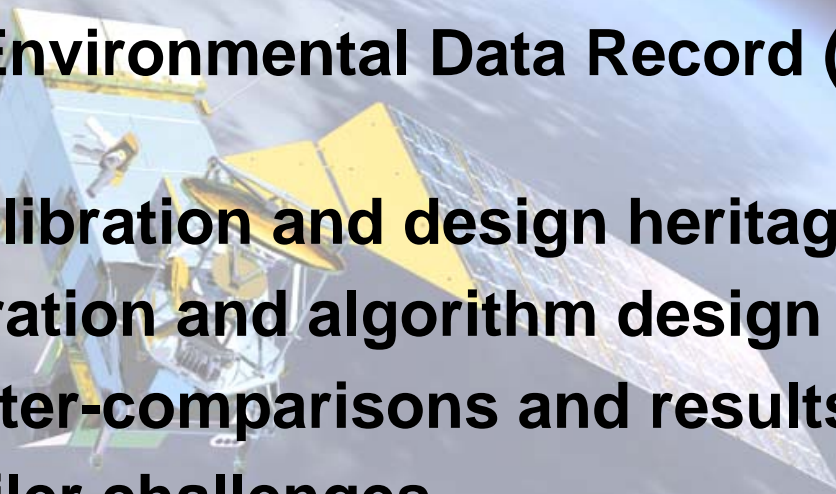
OMPS
Instrument Design

Total Ozone Mapper

UV Backscatter, grating spectrometer, 2-D CCD

TOMS, SBUV(/2), GOME(-2), OMI, SCIAMACHY

**110 deg. cross track, 300 to 380 nm spectral**

Limb Profiler

UV/Visible Limb Scatter, prism, 2-D CCD array

SOLSE/LORE, OSIRIS, SAGE III, SCIAMACHY

Three 100-KM vertical slits, 290 to 1000 nm spectral

Nadir Profiler

UV Backscatter, grating spectrometer, 2-D CCD

SBUV(/2), GOME(-2), SCIAMACHY, OMI

Nadir view, 250 km cross track, 270 to 310 nm spectral

The calibration concept uses working and reference solar diffusers.
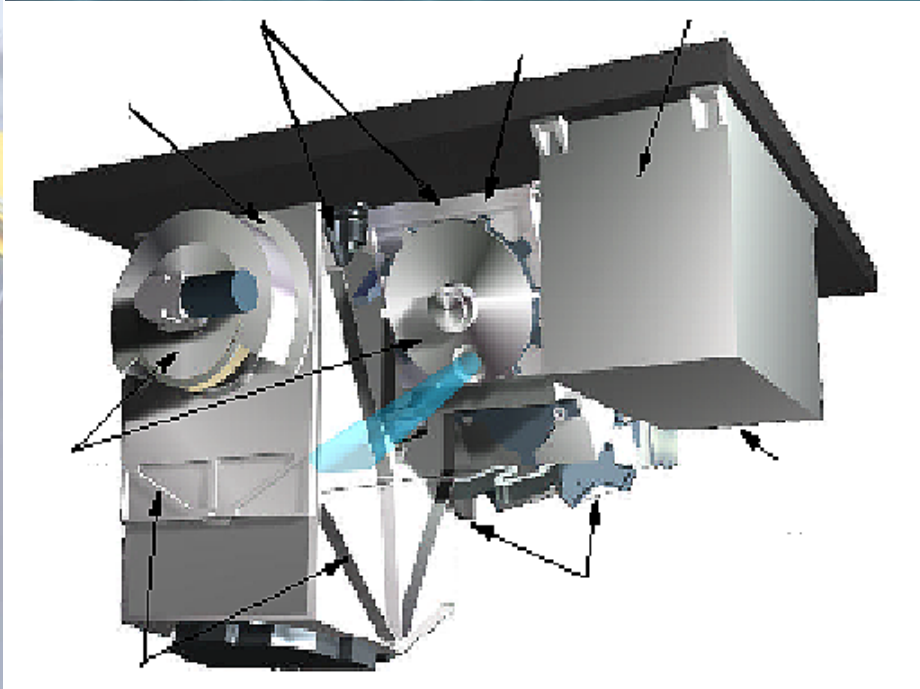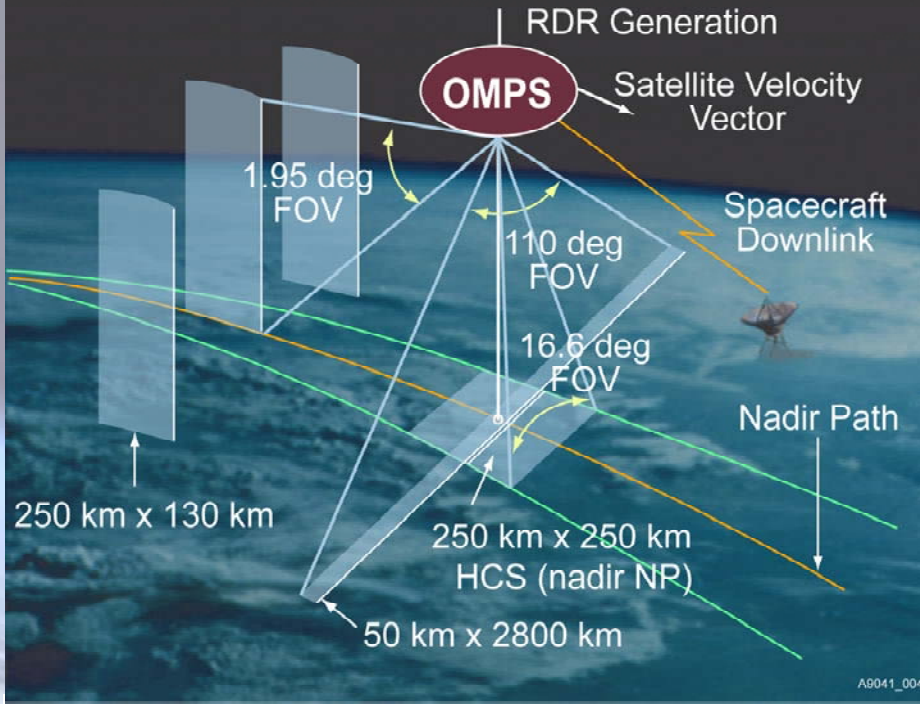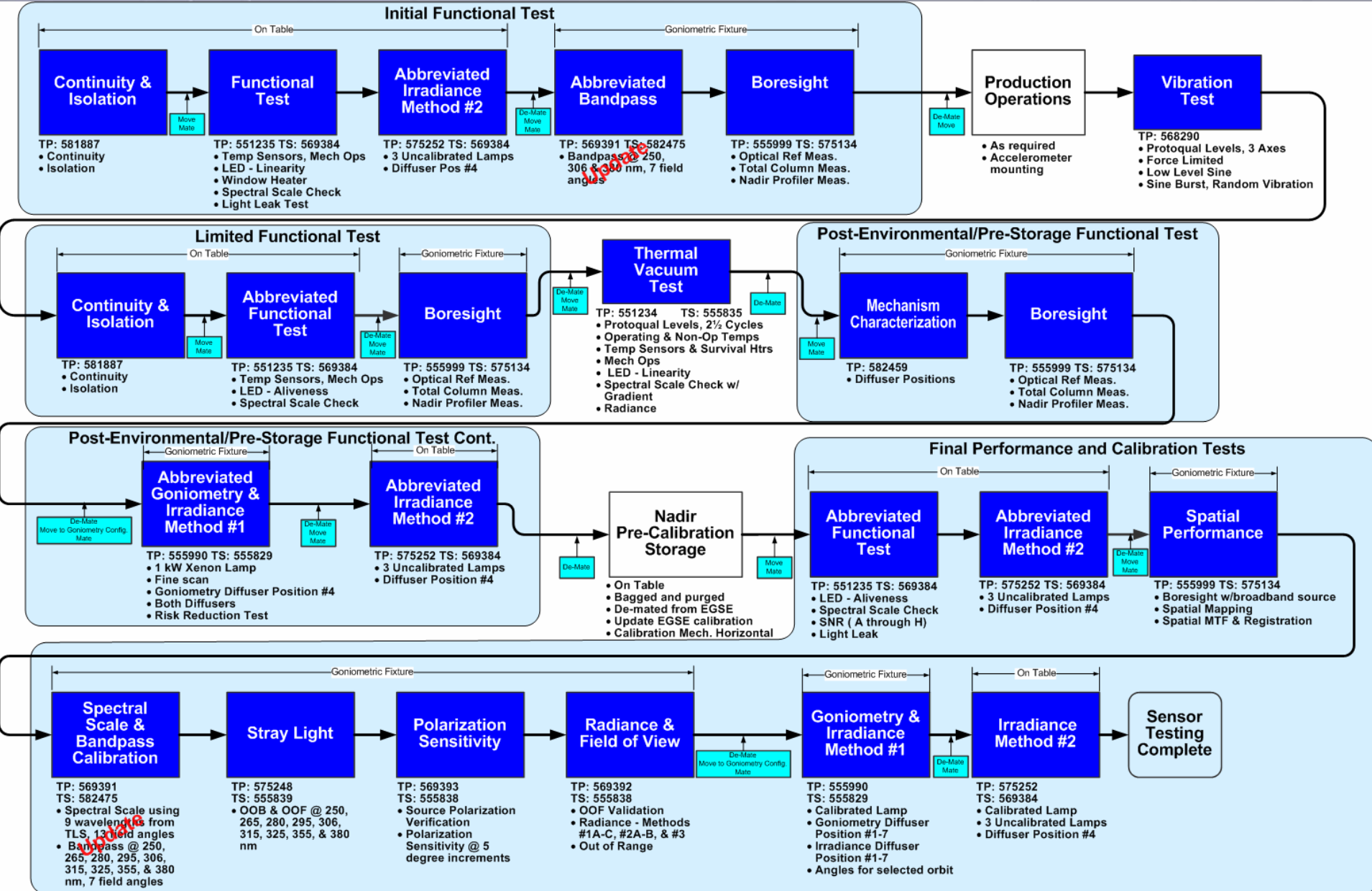
Nadir Sensor Acceptance Test Flow

Calibration Component Characterization and Traceability

| Calibration Component	Characteristic
Blocking Filter	Rejection Characteristics
Xe Lamp	Spatial Stability, Output Stability
Tunable Laser	Wavelength Accuracy, Output Stability
Integrating Sphere Output	Characteristics, Uniformity
FEL Lamps	Output Stability
Collimated Source Bench	Beam Uniformity
Spectralon Diffuser	Uniformity, BRDF versus wavelength
Aluminum Diffuser	BRDF versus wavelength
Nadir Flight Diffuser	Uniformity, BRDF versus wavelength
Limb Flight Diffuser	Uniformity, BRDF versus wavelength
Goniometric Fixture	Accuracy, Repeatability
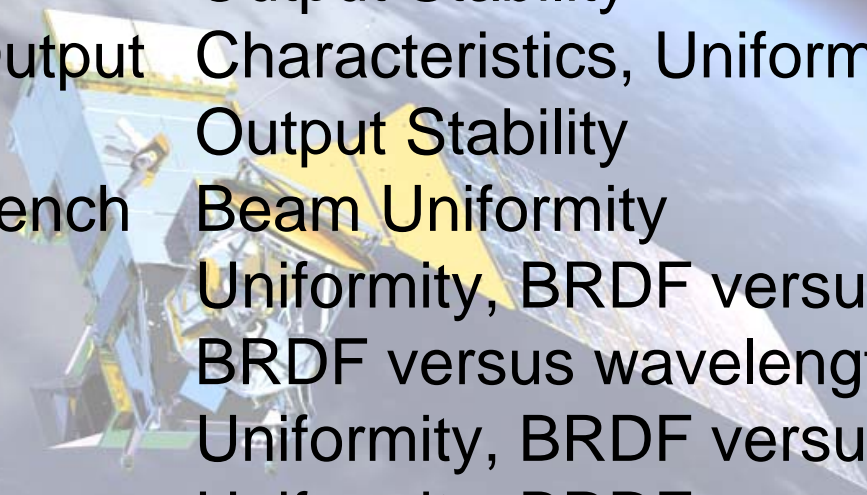
OMPS Sensor Database Generation Background

- **Mission success requires a seamless interface between the sensor characterization, the SDR and EDR input requirements, and cal/val and operational needs.**

- **Issue: Sensor characterization database generation not included in the subcontract – gaps identified between sensor characterization measurements data reduction plans and SDR algorithm input requirements and cal/val needs.**

- **Remediation: NGST worked with IPO, Ball and O3OAT to identify, confirm and close critical pre-launch gaps**

  - **Identification and assessment of sensor characterization databases required by SDRs**

  - **Review and assessment of sensor subcontract gaps**

  - **Coordination of effort across Integrated Program Teams**

| Sensor Characteristic	Size of Matrix	Need	Comments
Static Databases (measured on the ground, not updated on-orbit)			
Radiance Calibration Coefficients	spatial x spectral x 6 images x 2 integration times	SDR algorithm	Required for calibration of Earth scene radiances on-orbit.
Irradiance Calibration Coefficients	spatial x spectral x 6 images x 2 integration times	SDR algorithm	Required for calibration of Solar scene irradiances on-orbit.
Goniometric Calibration Coefficients	2 x spatial x spectral x m x n	SDR algorithm	Required for goniometric correction of solar calibration data on-orbit.
Spatial Resolution / Cell Shape / IFOV Shape	spatial x spectral x 6 images	Geolocation	Database consists of spatial response in angle space that can be projected onto the ground during a given geolocation.
Boresight to Sensor Reference Alignment	spatial x spectral x 6 images	Geolocation	Angular pointing of each macropixel required in geolocation.
LP Bandpass	51 x spatial x spectral x 6 images	SDR/EDR algorithm	Spectral response of each individual pixel and each macropixel.
Stray light correction	1 PSF fraction per channel per image	SDR algorithm	Extract the coefficients from the test data to predict LP stray light levels from measured signal
Dynamic Databases (measured and updated on-orbit, pre-launch ground measurement used as initial value, placeholder, and for testing)			
Channel Band Centers	spatial x spectral x 6 images	SDR/EDR algorithm	The actual wavelength calibration occurs using on-orbit solar calibration data. However, an initial pre-launch database will be constructed for potential SSPR algorithm testing.
Linearity and Lamp (LED) Signal	linearity: 4 x 16384 (4 amps, 14-bit) LED: n (each integration time)	Flight Software, SDR algorithm	Linearity and LED are updated using on-orbit data. This database will consist of linearity and LED signal as measured on the ground. It should be replaced with on-orbit linearity and LED signal computed using LED calibration measurements. It is include
Zero Input Offset	4	SDR Algorithm	Updated on-orbit. Provided here as the zero input offset as measured on the ground. Should be replaced on-orbit.
Sample Table (Bad Pixel Table)	780 x 364 x 2 integration times	Flight Software, SDR algorithm	Contains map of bad pixels. This database represents the initial database. Will be updated on-orbit using calibration measurements.
Dark Current	n x m x 6 images x 2 integration times	SDR Algorithm	Dark current is measured on-orbit. This database represents a placeholder of ground measured dark currents for use in potential SSPR algorithm testing.

Negotiated Nominal Databases Example Limb Profiler

Purposes of OMPS
Cal/Val Task Thread Content

1) **Activate the sensor, initialize the algorithms, and establish the regular operational functioning to produce SDRs and EDRs.**

2) **Compare orbital sensor characteristics to the laboratory measured characteristics.**

3) **Establish the calibrations of the sensor, place them into the SDR Algorithm, and measure the combined performance of sensor and SDR and EDR Algorithms.**

4) **Assess and understand the behavior of the sensor in time and under the influence of external forces.**

5) **Evaluate, when possible, whether the derived performance requirements are met by the SDRs.**

6) **Validate the EDR products, and when possible, check that the EDR requirements are met.**

7) **Perform regular measurements of sensor calibrations and update them in the Algorithm if necessary.**

8) **Monitor the long-term performance of the sensor, SDRs outputs, and EDR products for accuracy, completeness, and precision.**
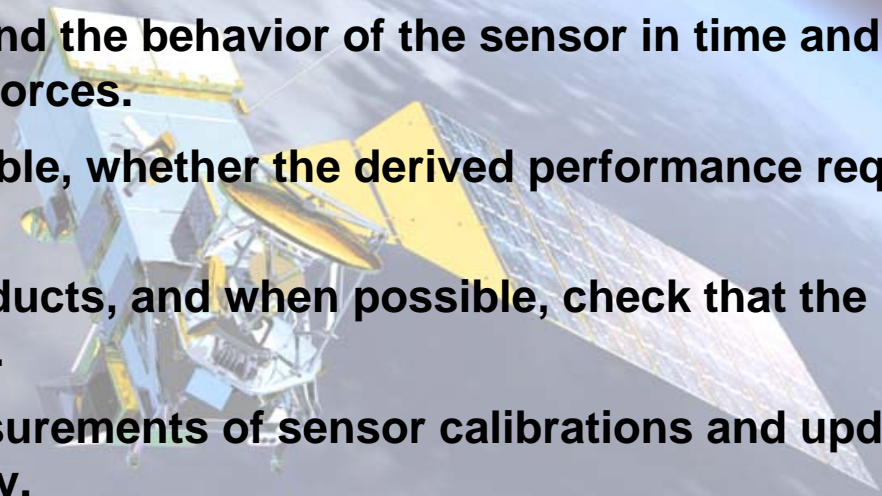
Additional Task Network Functionality

- **Provide details on capabilities of tools and programs to perform analysis.**

- **Formulate schedules and identify dependencies.**

- **Identify and document resources needed to performs tasks, e.g., ground-based measurements for validation.**

- **Help to determine and assign responsibility for task performance.**

Bundle EDR Ozone Products for One-Stop Shopping

Motivated by following principles:

1. Provide EDR and SDR product content as recommended in the ATBDs

2. Bundle retained validation IPs with the EDRs

3. Bundle information on ancillary and algorithm data choices

4. Make specific diagnostic IPs available within the EDR

5. Provide some specified SDR content in the EDR as well

6. Write out the heritage Version 6 Product Master Files as the Nadir Profiler delivered IP

7. Provide key existing algorithm parameters and values to track long-term stability Bundled Parameters are provided for calibration, validation, tuning, diagnostics, trending, characterization, and QA/QC

EDR and SDR	Environmental and Satellite Data Records
ATBD	Algorithm Theoretical Basis Document
IP	Intermediate Product
QA/QC	Quality Assurance/Quality Control

Operational Mode – Calibration State (Nadir and Limb)

Nadir Calibration Period from ta to t1 where t1 = ta + 118sec + (47-15)sec + 100sec + 575sec

Sensor	Measurement	When Required	Window in Orbit	ta + Cal. Time Required
Total Column	Solar	Working Diffuser - Weekly Reference Diffuser - 6 mo.	Term*-10° to Term* +10°	118 seconds
	Dark Current	Weekly	Term*+10° to Term*+67°	100 seconds
	Linearity	Weekly		575 seconds
Nadir Profile	Solar	Working Diffuser - Weekly Reference Diffuser - 6 mo.	At center TC diffuser position	47 seconds (15 second overlap with Total Column)
	Dark Current	Weekly	Term*+10° to Term*+67°	100 seconds
	Linearity	Weekly		575 seconds

Limb Calibration Period from tb to t2 where t2 = tb + 148sec + 100sec + 575sec

Sensor	Measurement	When Required	Window in orbit	tb + Length of Time
Limb Profile	Solar	Working Diffuser - Weekly Reference Diffuser - 6 mo.	Term*+17.1° to Term*+26.3°	148 seconds
	Dark Current	Weekly	Term*+26.3° to Term*+67°	100 seconds
	Linearity	Weekly		575 seconds

* Term = Solar Illumination Terminator

Ozone Retrieval Algorithms

- ## Total Ozone
  - Ratios of Earth radiance to Solar Irradiance
  - Pairs and triplets of channels + standard profiles

- ## Profile Ozone
  - Limb Profiler
    - Radiances normalized to reference height values
    - Pairs and triplets of channels
    - Maximum likelihood
  - Nadir Profiler
    - Ratios of Earth radiance to Solar Irradiance
    - Maximum likelihood + *a priori*

Algorithm Theoretical Basis Documents for OMPS are available at
http://www.npoesslib.noaa.gov

Internal and Soft Calibration and Validation Sequence for Total Ozone

1. Check 331-nm reflectivity channel calibration by using global distributions of reflectivity – minimum ocean (4%) and land (1%) reflectivity, maximum global reflectivity and ice radiances (Greenland and Antarctica).

2. Check agreement between 360-nm reflectivity and 331-nm reflectivity for scenes with reflectivity greater than 80%.

3. Compute total ozone for nadir measurements from B-pair (317.5-nm and 331-nm) in the tropics and compare to expected values.

4. Check agreement of other ozone sensitive channels/pairs with the B-pair results.

5. Check agreement between zonal means at each satellite view angle and the nadir zonal means.

6. Compare ozone and reflectivity results for different channels and pairs as functions of solar zenith angles and reflectivity.

Solar Backscatter UltraViolet 2 (SBUV/2) Product Validation

- **Total ozone versus Dobson and Brewer**
  - Station calibration and continuity (CMDL)
- **Profile ozone versus:**
  - Ground-based Lidar and Microwave (NDSC)
  - OMI and MLS (AVDC)
  - Umkehr and Sondes (WOUDC)
  - Occultation (SAGE, HALOE and POAM)
- **Archives (CLASS, DAAC and SAFs)**
- **Comparisons via assimilation, trajectory mapping and Potential Vorticity / Theta Coordinates**

Monthly Average Differences between SBUV(/2) Overpass and Ground-based Dobson Network Total Ozone Estimates
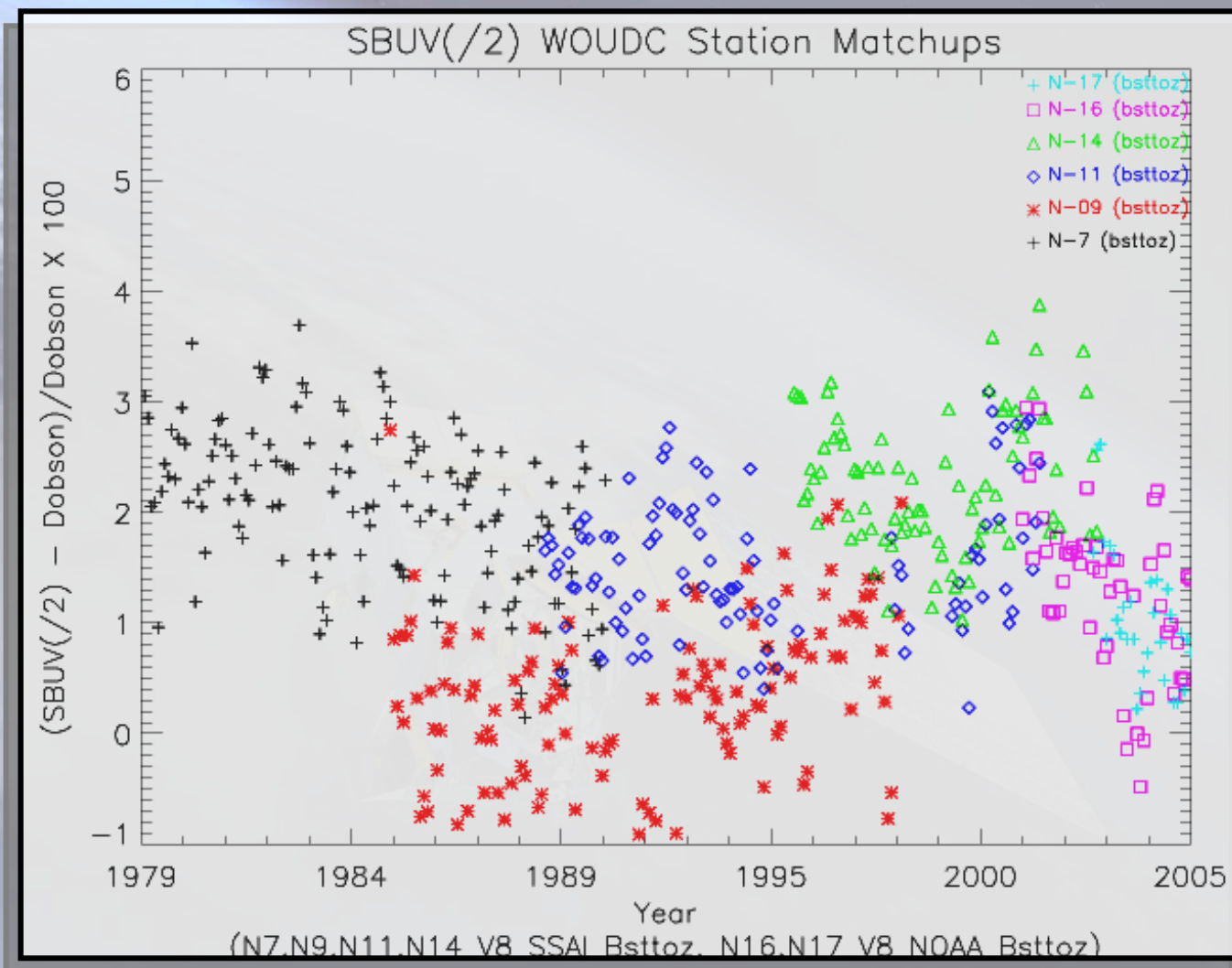
Seasonal Variations of Layer Ozone over Lauder, New Zealand (45S, 170E)
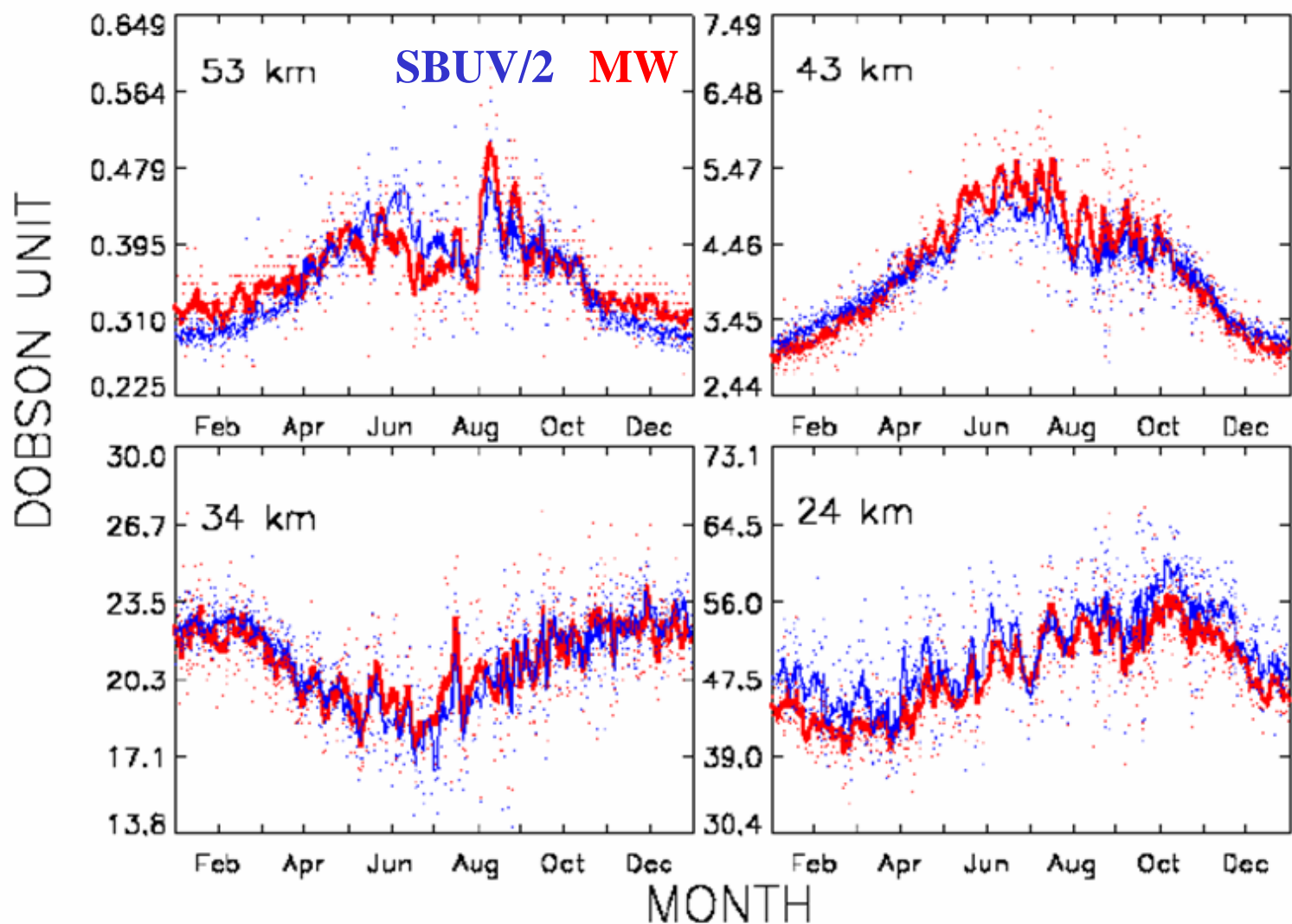
Latitude Dependence NOAA SBUV/2 and Advanced Microwave Limb Sounder

Zonal means, 30.00 to 10.00 hPa 2005/01/01
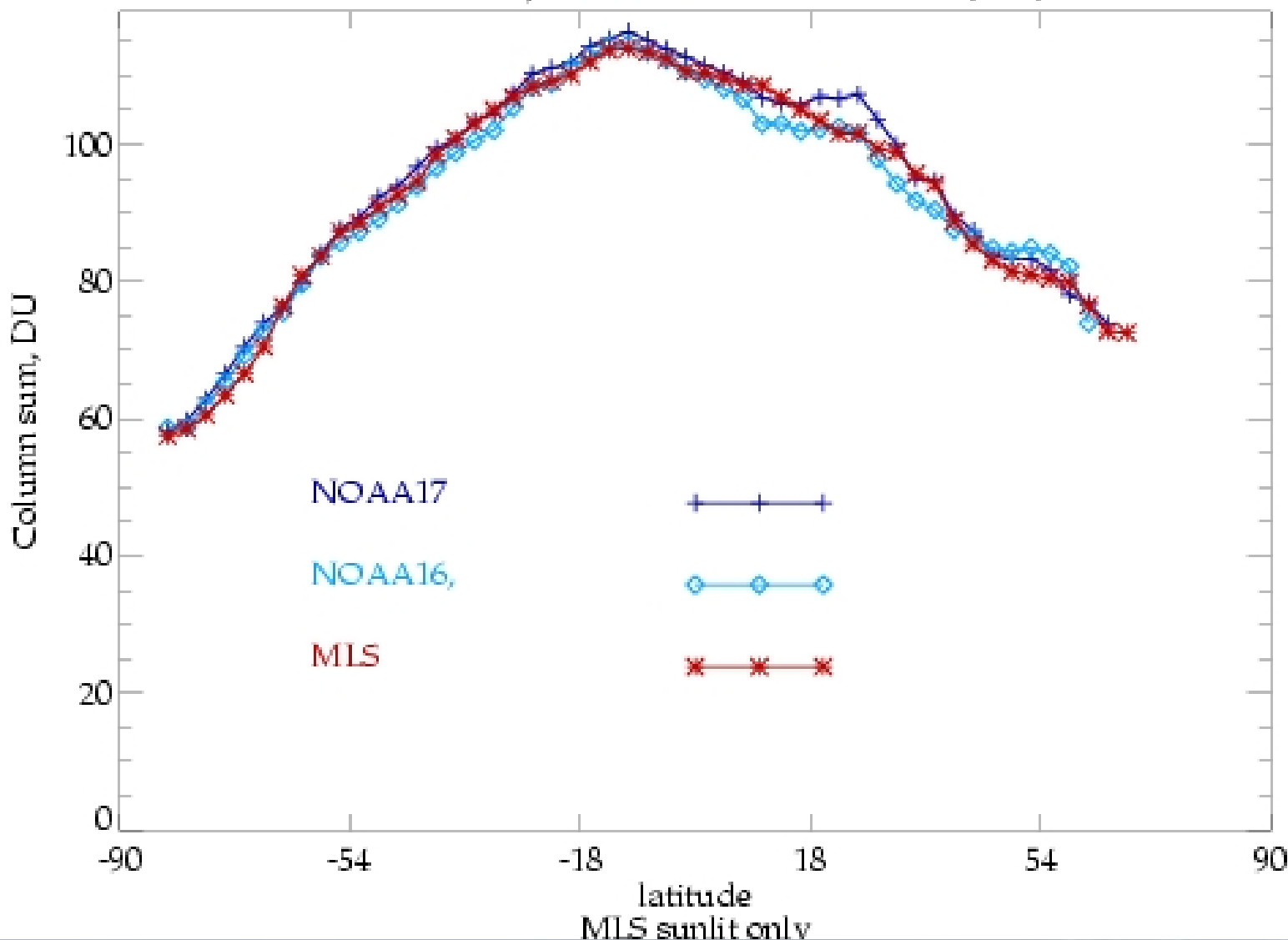
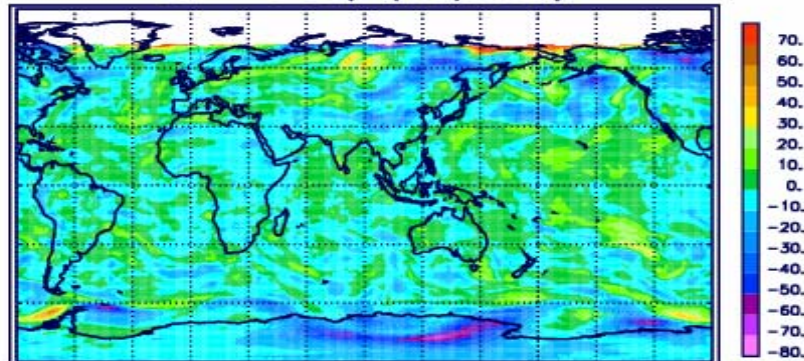# Comparison of Ozone Monitoring Instrument (OMI) and Global Forecast System (GFS) Total Ozone
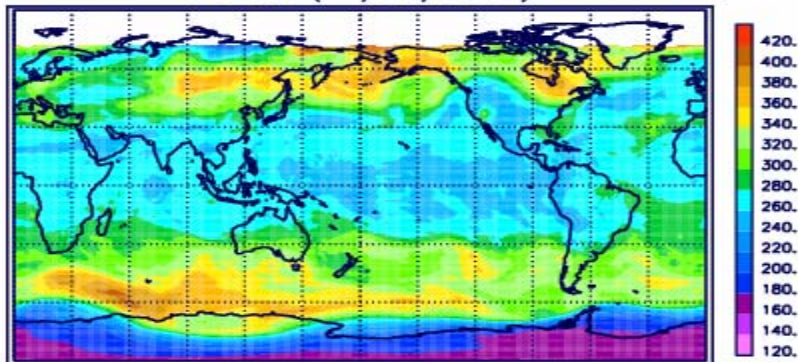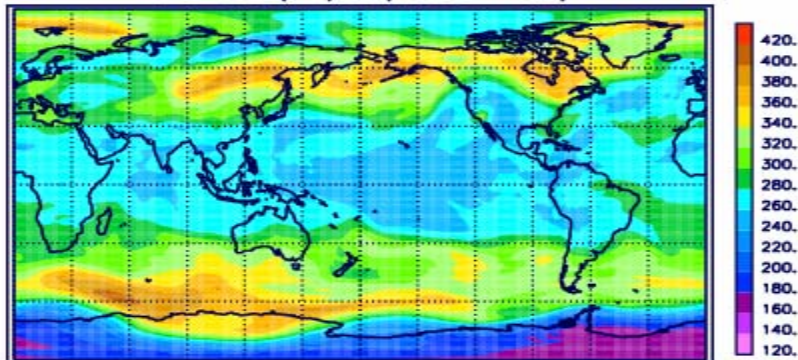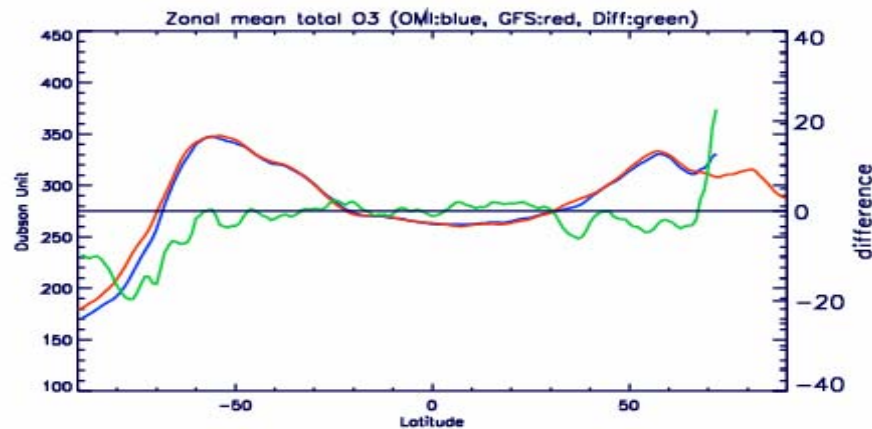
Challenges for Limb Profiler Calibration
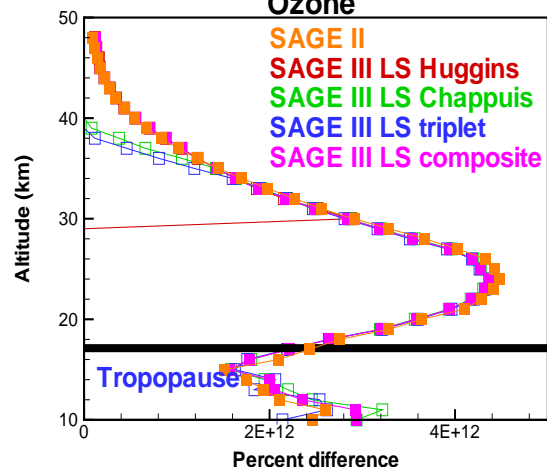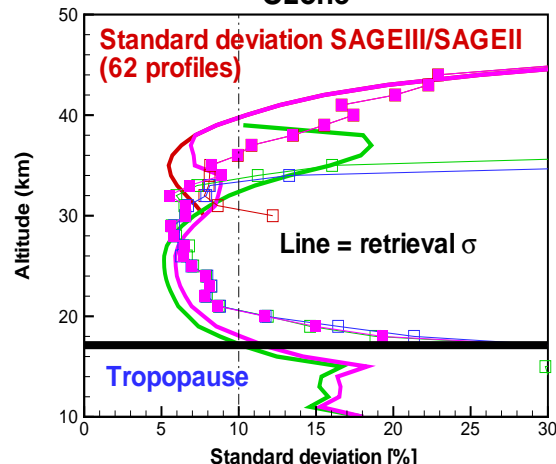
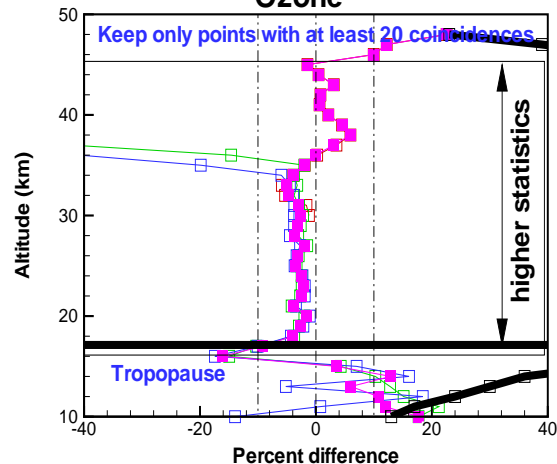**Complexity of stray light corrections**

Need to match the vertical resolution and field of view
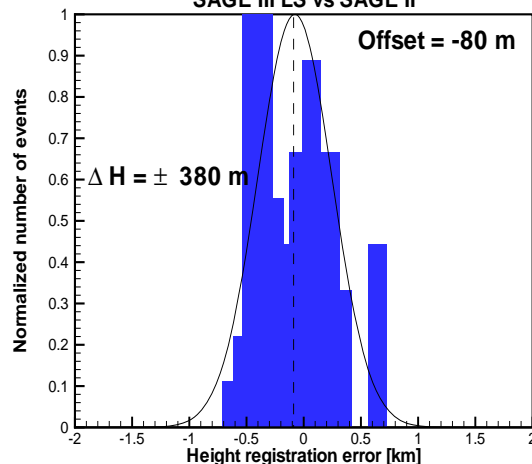
May need to make height/pressure conversions

Need to identify pointing errors and height shifts

<u>Figure from work by D. Rault NASA LaRC</u>

# Summary of Activities and Plans

- **Extensive program of instrument calibration and characterization**

- **Generation of SDR and EDR parameters and Look-Up-Tables and in-flight calibration programs**

- **Identification and coordination of Cal/Val Tasks**

- **Identification of diagnostic and QC/QA parameters**

- **Coordination between in-orbit calibration concept and algorithm measurement expectations**

- **Extensive experience with soft calibration and validation resources from current ozone programs**

- **Challenges for validation of improved ozone profile products**
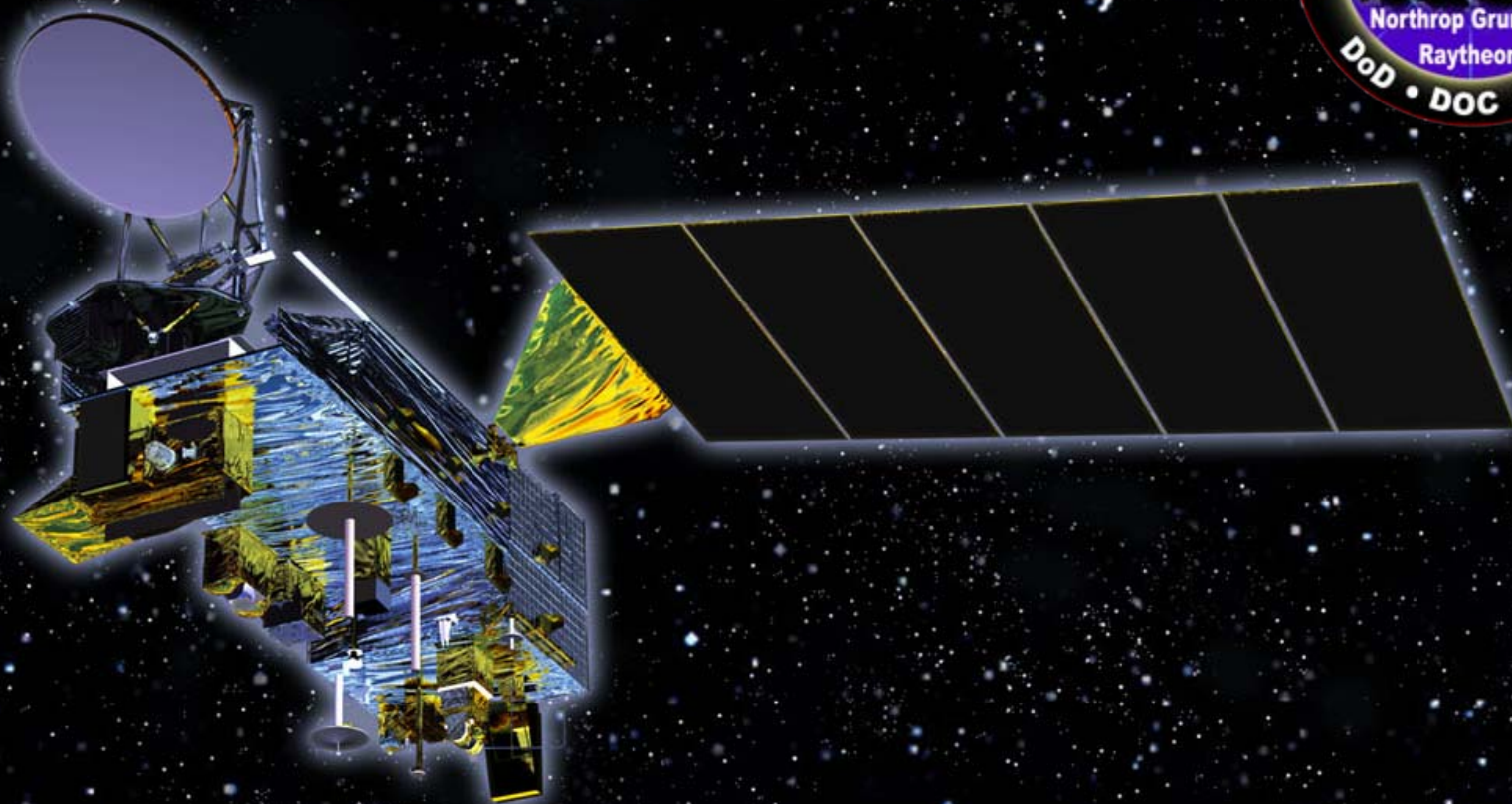
National Polar-orbiting Operational Environmental Satellite System